National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

Re-Engineering the Mission Operations System for the Prime and Extended Mission

Spitzer Space Telescope

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Mission Overview

Phase	Start / End Date
Launch	2003-08-25
In-Orbit Checkout and Science Verification (IOC/SV)	2003-08-25 / 2003-12-01
Prime (Cryogenic) and Primary Plus	2003-12-01 / 2009-05-15
IRAC Warm Instrument Characterization (IWIC)	2009-05-16 / 2009-07-27
Extended (Warm) Mission	2009-07-27 / 2012-12-31

Science Objectives

Cryo Mission:

- Deep surveys of oldest galaxies
- Evolution and structure of ultra-luminous galaxies and quasars
- Search for Brown Dwarfs
- Evolution of stellar disks and planetary systems

Warm Mission:

- Study properties of extra-solar planets
- Study galaxies during the first one billion years after the Big Bang
- Complete census of the galaxy for young stars
- Determine cosmic distance scale in the local universe

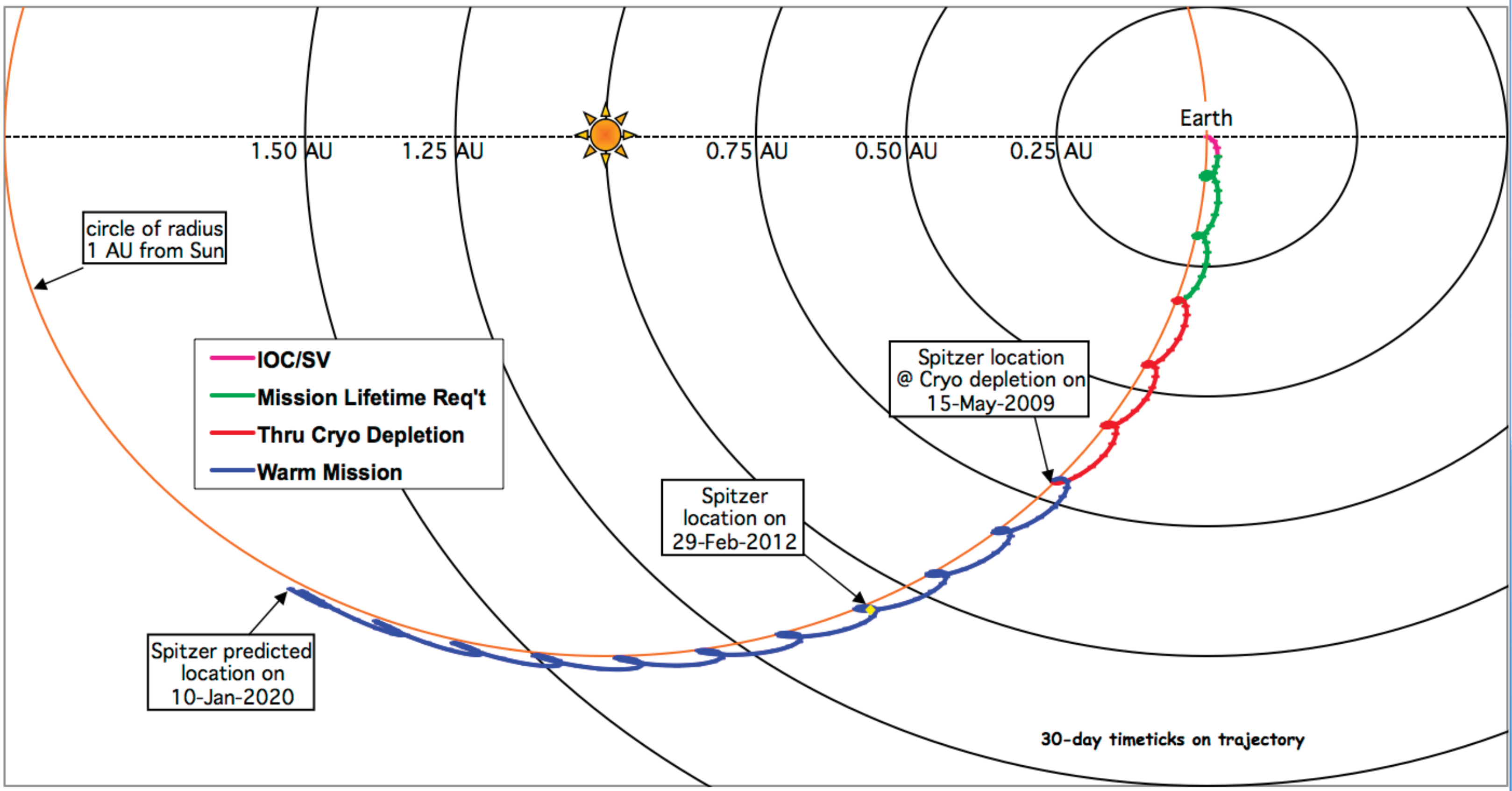
Instruments

- Three science instruments
  - *IRAC – Infrared Array Camera*
    - Bands: 3.6 μm, 4.5 μm, 5.8 μm, and 8.0 μm
  - *MIPS – Multi-band Imaging Photometer*
    - Bands: 24 μm, 70 μm, and 160 μm
  - *IRS – Infrared Spectrometer*
    - Bands: 5.2 μm – 14.5 μm, 9.9 μm – 19.6 μm, 14.0 μm – 38.0 μm, and 18.7 μm – 37.2 μm

- In the Cryogenic Mission, only one instrument was on at a time for a sequence duration of one to three weeks.
  - *Primary mirror operates between 5.6 K and 12 K.*

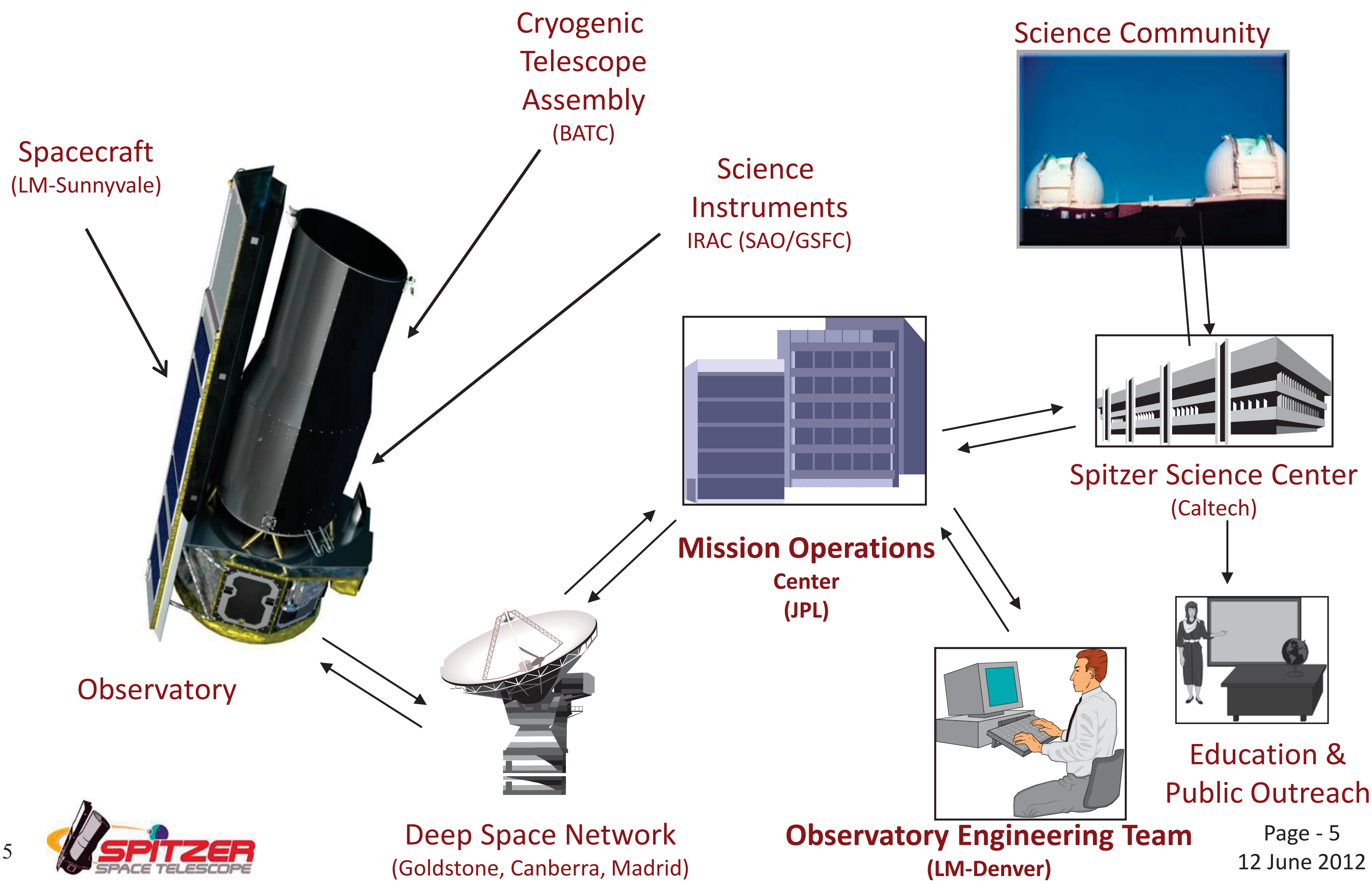
- In the extended Warm Mission, only two bands of IRAC, 3.6 μm and 4.5 μm, will produce valid science data.
  - *Primary mirror operates at ~26 K*

Orbit



Solar Orbit projected onto the Ecliptic plane. In the rotating coordinate frame shown here, the Earth-Sun line (X-axis) is held fixed and the Earth is at the origin. Distance contours from Earth are shown @ 0.25 AU steps.

Distributed Operations

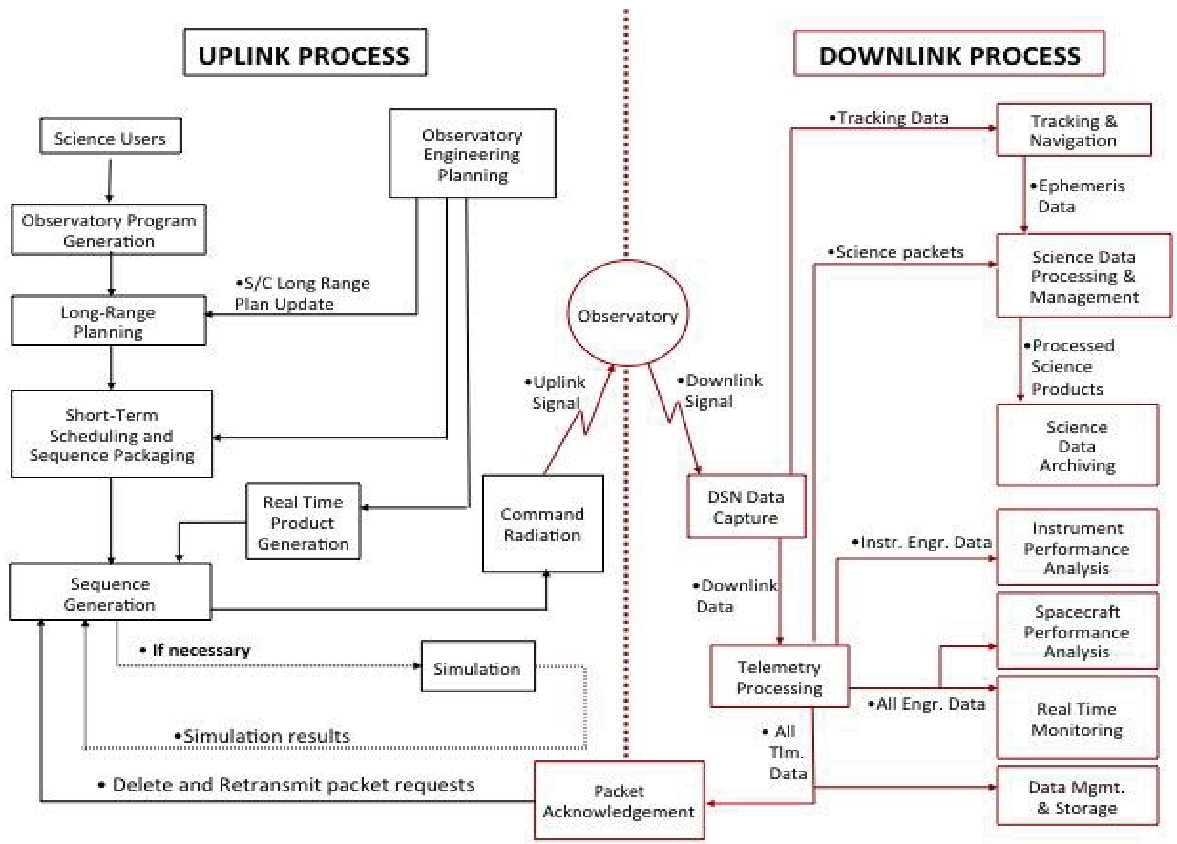


Definition of MOS

- The Mission Operations System (MOS)
  - *Contains the people, teams, processes and procedures*
  - *The Ground Data System (GDS) is a subset of the MOS*
    - The GDS contains computers (hardware and software), networks and physical facilities

- The MOS architecture is divided into uplink and downlink processes.
  - ***Uplink processes****: The procedures and tools for developing command products for spacecraft and science operations*
  - ***Downlink process****: The procedures and tools responsible for receiving data transmitted by the spacecraft and routed to various customers such as navigation, science teams, spacecraft and instrument engineering, and real-time mission control.*

Uplink and Downlink Processes



Re-engineered Phases Highlighted

Phase	Start / End Date
Launch	2003-08-25
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* Mission Phases Re-engineered

Driving Factors for Re-engineering

- Changes in mission capability
  - *Spitzer's loss of cryogen has redefined the science objectives from operating with three infrared sensors to one*

- Reduction in funding profile from prime to extended mission phases
  - *Re-engineering is necessary for the optimization of the MOS with declining resources*

- Missions with a long life cycle should take advantage of technological advances occurring outside of the space industry
  - *Example: Rapid rise of smartphone usage not only improve communications but also places desktop computing capabilities in the palm of one's hand*

- Incorporation of lessons learned
  - *Re-engineering is a method to eliminate unforeseen design inefficiencies that is often revealed as the MOS matures in the operations phase of the mission life cycle*

Spitzer's Re-engineering Path

Primary (Cryo)
- Operating from baseline mission design

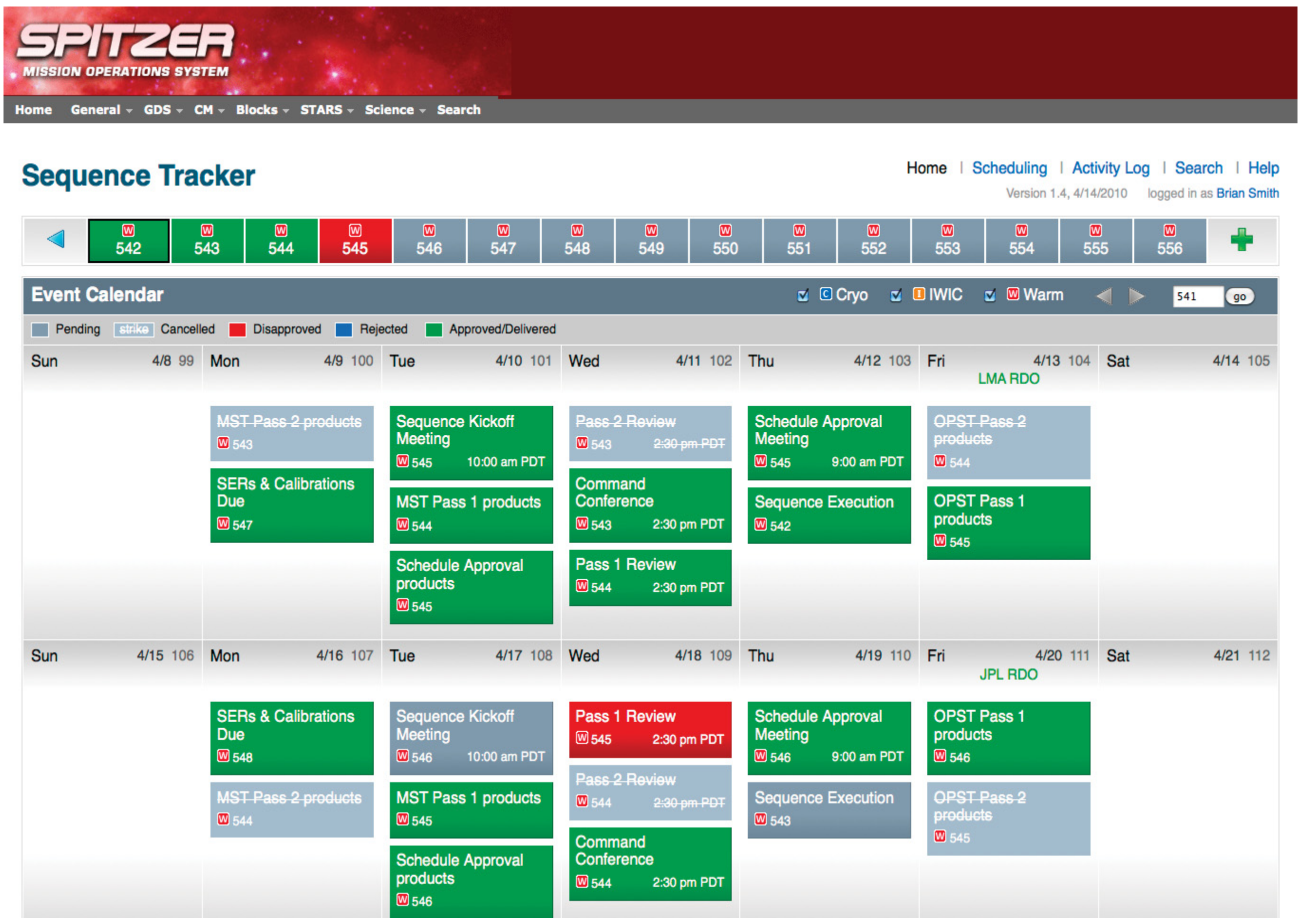
Primary Plus (Cryo)
- Lessons Learned from Mature MOS

Extended (Warm)
- Gain in MOS Operational Efficiency

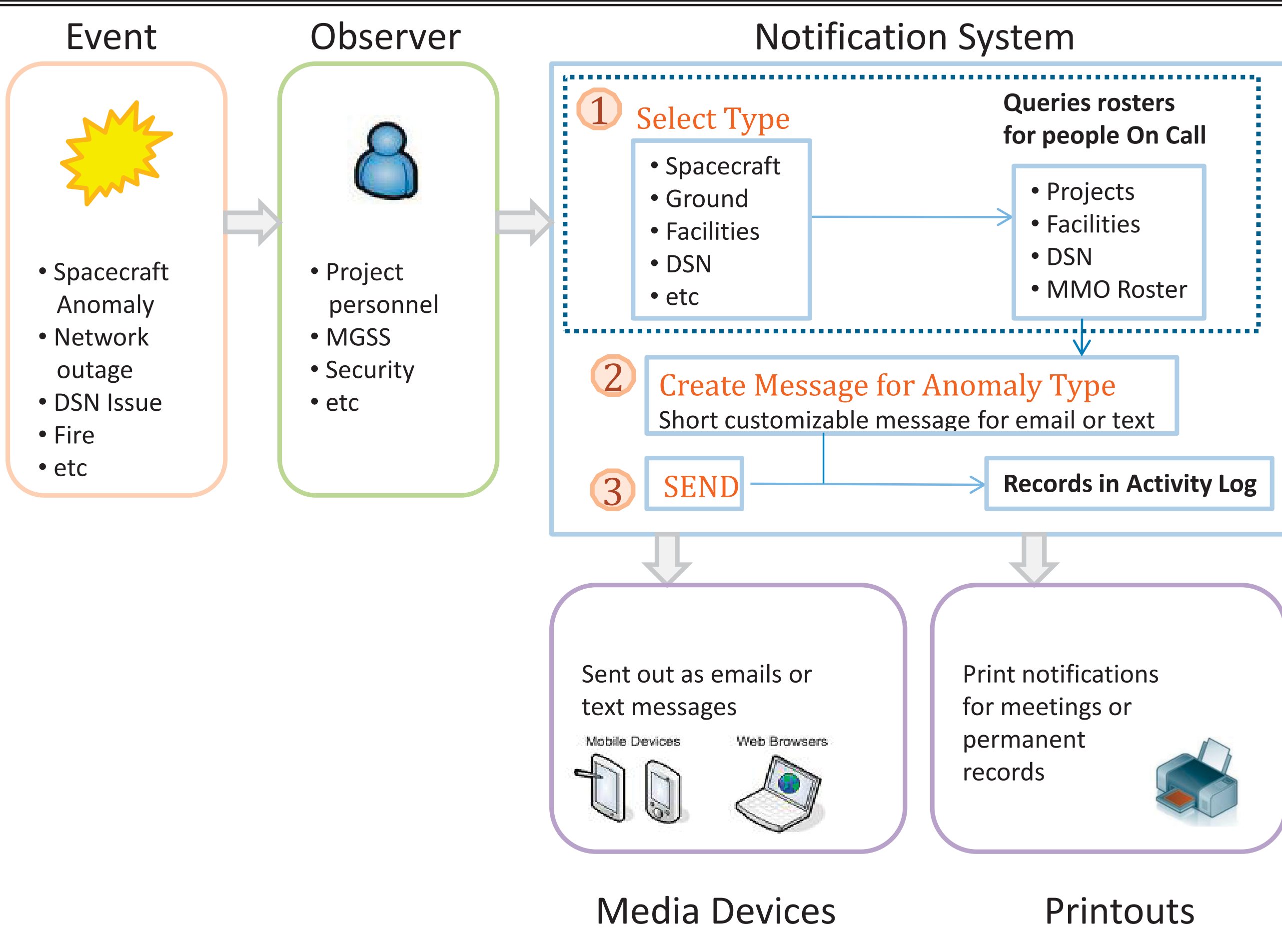
Re-engineered Elements

MOS Elements	Prime (cryogenic) Mission	Primary Plus	Extended
Sequence Schedule and Review	• Paper Schedule • Email and Fax	• Automated Web Calendar • Discussion Threading with Traceability/Status update • (Sequence Tracker)	• Ingesting From Other Databases • Electronic Approval
Planning Products	• Non-optimized Data Collection	• Data Volume based on Predicts • (MMC Prediction Tool)	• Antenna Elevation Angle
Uplink Summary	• Hardcopies	• Electronic Forms/Approval	• Editing Capability
Telecom Link Margin	• Unrestricted (34 m to 70 m antennas)	• Extrapolated Telecom Link Margin Analysis • Eliminated Data Dropouts Due to 1-way/2-way mode changes	• Antenna Scheduled to Optimize Link Margin
Packet Acknowledgement	• Nominal PAP	• No change	• Express PAP
Duty Roster	• Laminated Cards	• Web Based Roster with Electronic Notification	• Smartphone Interface
Workforce	• Dedicated Teams	• Limited Cross Training	• Multi-rolled Staff

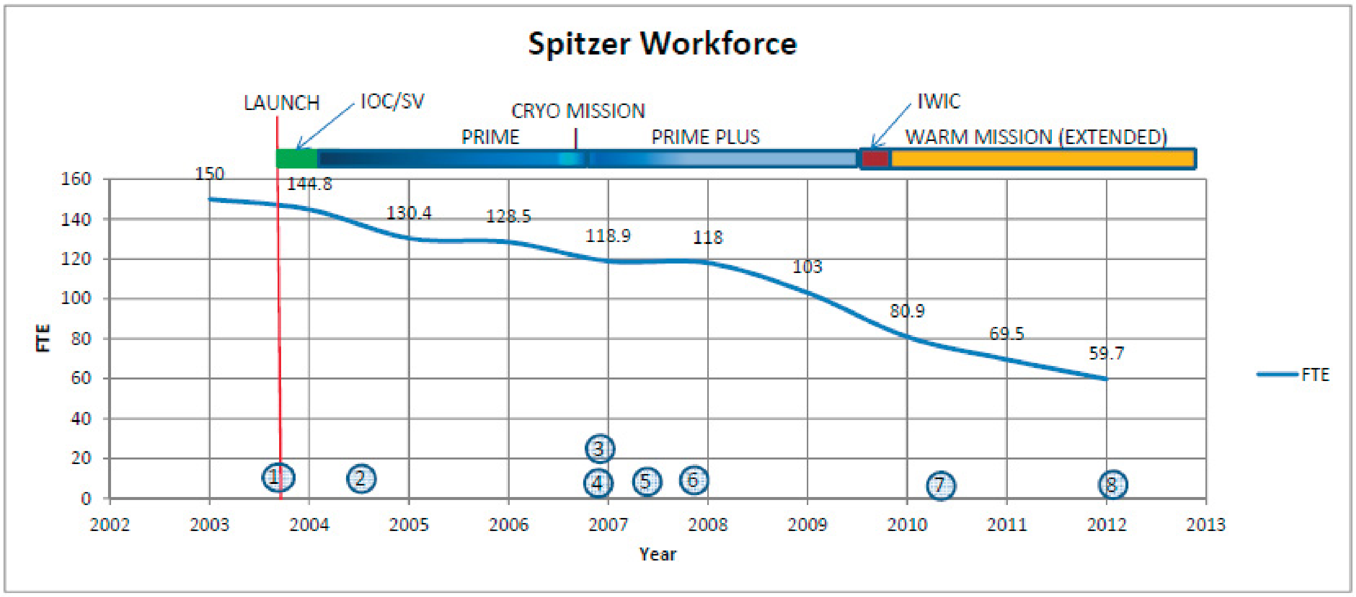
Sequence Tracker



Duty Roster Notification System



Spitzer Workforce Profile



Mission Phase			
8/25/2003		Launch	(Vehicle Delta II 7920H)
8/25/2003	- 12/1/2003	IOC/SV	
12/1/2003	- 5/15/2009	Prime Cryo Ops	
5/16/2009	- 7/27/2009	IWIC	
7/27/2009	- current	Warm Mission	

Enhancements

1 - 2003 Electronic Contact List (Duty Roster)
2 - 2004 Duty Roster Phase 1 (contact Info and notification via local browser)
3 - 2006 MMC Prediction Tools (9/1/2006)
4 - 2006 Anomaly Notification (added to Duty Roster - Sept 2006)
5 - 2007 Express PAP (2/13/2007)
6 - 2007 Sequence Tracker (12/10/2007)
7 - 2010 Elevation Angles - 4/14/2010)
8 - 2012 Duty Roster Phase 2 (Mobil App)

Conclusion

- Re-engineering eliminates unforeseen design inefficiencies that is revealed as the MOS matures in the operations phase of the mission life cycle.

- Re-engineering is an integral part of Systems Engineering

- NASA Systems Engineering Handbook dedicates only 33% to operations.

- We suggest the following improvements in the Handbook
  - *Suggest Phase E (operations) to include a formal re-engineering evaluation*
  - *Propose the addition of an optional "extended mission" phase between Phase E (operations) and Phase F (closeout).*

Acknowledgements

The research and development described here was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

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The Sombrero Galaxy's Split Personality

This Spitzer image taken on April 24, 2012 shows the Sombrero galaxy -- named after its appearance in visible light to a wide-brimmed hat -- is in fact two galaxies in one. It is a large elliptical galaxy (blue-green) with a thin disk galaxy (partly seen in red) embedded within. Previous visible-light images led astronomers to believe the Sombrero was simply a regular flat disk galaxy.

Spitzer's infrared view highlights the stars and dust. The starlight detected at 3.5 and 4.6 microns is represented in blue-green while the dust detected at 8.0 microns appears red. This image allowed astronomers to sample the full population of stars in the galaxy, in addition to its structure.

The flat disk within the galaxy is made up of two portions. The inner disk is composed almost entirely of stars, with no dust. Beyond this is a slight gap, then an outer ring of intermingled dust and stars, seen here in red.

Back-up Material

Back-up Material

- The primary mirror is 85 cm in diameter. It is made of beryllium and was cooled to between about 5.6 K and 12 K, depending on the instrument in use. The field-of-view angle of the telescope is 32′ (32 arcminutes). The focal length is 10.2 m. The total mass of the spacecraft at launch was 950 kg, including 50.4 kg of liquid helium cryogen.

- Spitzer is in a heliocentric, Earth-trailing orbit. It follows the Earth around the Sun. Its orbit is slightly more elliptical than the Earth's, and most of the time it is farther away from the Sun than the Earth is, so it slowly recedes from Earth at about 0.1 AU/yr.
  - *Current Orbit Information (Geocentric)*
    - *Distance = 161,641,095 km (~1.08 AU)*
    - *One-way light time = 539.131 s (~8m:59s)*
    - *Right Ascension (EME J2000) = 100.93 deg*
    - *Declination (EME J2000) = 22.66 deg*

Back-up material

- The spacecraft uses its on-board pointing control system to shade itself with its solar arrays for reasons of thermal control. As such, at any given time, it can see only about 31.5% of the full sky. This area is called the Operational Pointing Zone (OPZ). There are two zones of the sky around the ecliptic poles that are always in view. Objects in the ecliptic plane are in view for two periods of forty days each per year.